Hyperspectral Imaging of the Coastal Ocean

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LONG-TERM GOALS

The Navy has a requirement to rapidly and covertly characterize the coastal environment in support of Joint Strike Initiatives. Over the past 14 years we have demonstrated that spaceborne hyperspectral remote sensing is the best approach to covertly acquire data on shallow water bathymetry, bottom types, hazards to navigation, water clarity and beach and shore trafficability to meet those requirements. The long term goal of this work is to put a hyperspectral imager capable of making the appropriate measurements in space to demonstrate this capability.

OBJECTIVES

The objective of this work is to put a hyperspectral imager in space to demonstrate the ability to covertly acquire data on shallow water bathymetry, bottom types, hazards to navigation, water clarity and beach and shore trafficability. The proposed activities are designed to take avantage of flying the Hyperspectral Imager for the Coastal Ocean (HICO) on the International Space Station (ISS). Our work includes advancing methods of on-orbit calibration and product validation, and processing and analyzing hyperspectral data of the coastal ocean. As HICO Project Scientist I work to enhance community awareness of the need for and utility of hyperspectral imaging of the coastal ocean.

APPROACH

I have focused on two tasks over the two year period of this grant (FY 08-09):

1. Continue to advance the development and validation of ocean color products from hyperspectral imaging. This has included the collection and processing of in situ bio-optical data and the testing of algorithms for processing of hyperspectral data. I Completed publications on in situ and PHILLS airborne hyperspectral data. The first is on the in situ optical data form all three sites, the second is on scaling of hyperspectral data to resolve coastal features. We also developed protocols and proceedures for the on-orbit calibration and product validation for HICO to begin next month.

2. Prepare for HICO on the ISS. At the request of Mike Corson (Naval Research Laboratory) the Principal Investigator for HICO I am the Project Scientist for HICO. This has included setting the science requirements and working with the NRL scientists and engineers to make sure HICO meets those requirements. I am working with the NRL team to process the HICO data, validate the on-orbit

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calibration and products and make it available for scientific studies of the coastal regions. HICO is now operating on the International Space Station (ISS).

WORK COMPLETED

Our work is focused on the coastal ocean and a major issue for the coastal ocean is that the standard case 1 algorithms used to calculate chlorophyll and other water properties assume that phytoplankton with an associated level of Colored Dissolved Organic Matter (CDOM) and water itself are the only optically active components. In coastal waters high levels of CDOM from rivers and coastal runoff, large phytoplankton blooms, sediments from rivers, or resuspension from the bottom are all significant optical components that need to be considered as part of the optical signature. For example the standard MODIS and MERIS products give false high chlorophyll values for the Columbia River Plume (**Fig. 1**). The MERIS neural network (algal 2) algorithms are designed for European coastal waters and do a better job of separating chlorophyll and suspended sediments. We are working to modify them for Oregon coastal waters and eventually for use with HICO data. Note also that the 1 km MODIS data does not sample the Columbia River mouth including the mixing zone that is order 50 km from the coast. MERIS 300 m data does a better job of imaging the estuary but HICO has 100m GSD and full spectral data which will be ideal for this example river system.

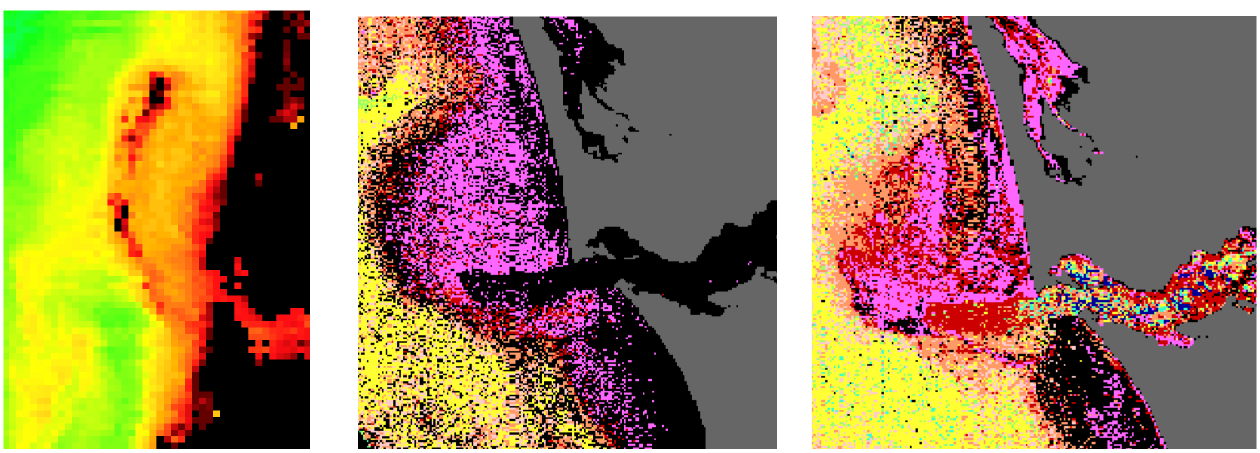


Figure 1. Satellite ocean color images of the Columbia River estuary and plume on September 10, 2009. Left, is the MODIS standard 1000 m chlorophyll product. This algorithm gives false high values for the river system(red in this color scale) due to the high suspended sediments in the river water. The large pixels do not image the river mouth effectively. Center is the MERIS 300 m standard chlorophyll product (algal 1). The river mouth and near shore plume are black indicating the algorithm does not give a valid product for these waters. Right is the MERIS neural network coastal chlorophyll product (algal 2) which shows reasonable chlorophyll values for the river mouth and nearshore plume. The 300 m MERIS pixels do a much better job of imaging the river mouth.

HICO data will be available beginning in October 2009 following launch and system checkout in September. The APS-HICO processing system includes the automated production of the standard products currently produced from MODIS data by the team led by Bob Arnone at the Ocean Sciences Division at NRL at the Stennis Space Center, MS. It will also produce a calibrated spectral image cube with the full 128 spectral channels of HICO data. Several experimental products will be produced from that data. Zhongping Lee will apply his Hyperspectral Optimization Process Execution (HOPE) algorithms to produce coastal products including bathymetry and bottom type for optically shallow water. These algorithms were developed using Hyperion data (Lee et al, 2007) and we expect them to work well with HICO data that will have much better radiometric quality and 20 times the signal-to-noise ratio of Hyperion data. These algorithms specifically include CDOM, chlorophyll and suspended sediments as well as bathymetry and bottom properties. We have installed this software for use with HIOC data and will test and evaluate the products from the HOPE algorithms for the Columbia River system.

Many researchers working in the coastal ocean have moved away from the case 1 waters assumptions and are directly calculating Inherent Optical Properties (IOPs) from remote sensing data (IOCCG, 2006). To develop and validate IOP algorithms for coastal waters it is essential to collect profiles of IOPs and simultaneous water samples for further analysis for phytoplankton, suspended particulates and CDOM. To accomplish this we developed the Profiling Optics and Water Return (POWR) system (Rhea et al., 2007). POWR is used to measure temperature, salinity and a suite of IOPs of the upper 100 m and collect up to 8 water samples at selected depths. Data is displayed in real-time on the ship and that data can be used to select the depth for water samples. We are using the data collected with POWR to characterize a diversity of coastal environments. Using this system in we conducted a study of optical scattering and backscattering of particulates for three coastal sites that represent a wide range of the optical properties found in U.S. coastal waters (Snyder, et al. 2008).

In preparing for HICO we have in addition been collecting profiles of downwelling irradiance and upwelling radiance using a Satlantic HyperPRO (**Fig. 2**). The HyperPRO is a free falling optical profiling system that collects profiles of spectral Lu and Ed and chl fluorescence, backscatter, T and salinity. The system is calibrated by Satlantic and we use the Satlantic software for processing including all of the latest corrections based on NIST calibrations. This system produces high quality measurements of spectral remote sensing reflectance (Rrs) for direct comparison to the HICO data after atmospheric correction. The HyperPRO data together with other data collected on each station including HPLC pigments, productivity, CDOM, suspended sediments are placed in a data base with web access.

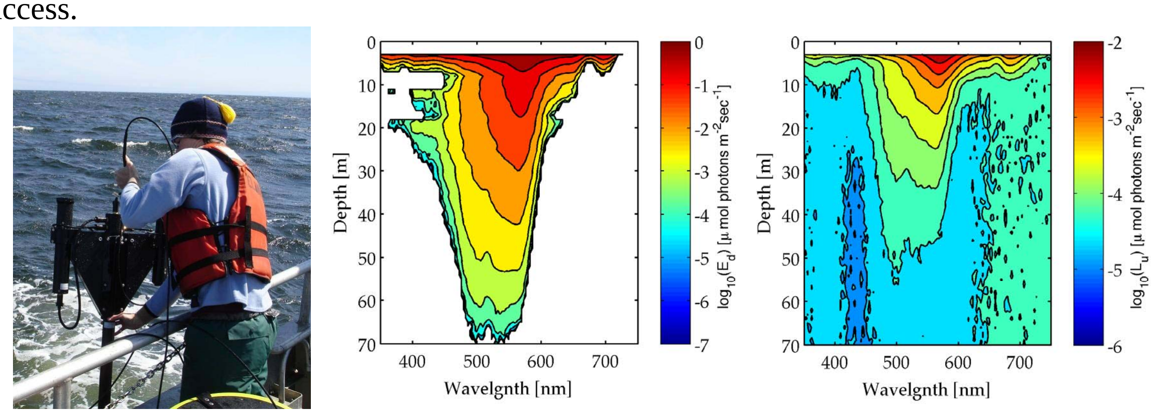


Figure 2. Collecting HyperPRO data and an example data set from the MILOCO cruise off the Oregon coast taken June 4, 2009. (Left side of the side of the figure shows a research associate lowering the HyperPRO instrument over the side of a small research vessel. The center panel shows the depth profile of the spectra of downwelling irradiance. The right panel shows the depth profile of the spectra of the upwelling radiance collected with the HyperPRO instrument.)

Current ocean color sensors, for example SeaWiFS and MODIS, are well suited for sampling the open ocean. However, coastal environments are spatially and optically more complex and their characterization require higher spatial resolution sensors equipped with additional spectral channels (**Fig. 1**). In an earlier study (Davis, et al, 2007) we analyzed the spectral characteristics and spatial scales of variability in airborne hyperspectral data of a harmful algal bloom in Monterey Bay, CA using semivariogram analysis. The results indicated the need for a channel near 709 nm (as found on MERIS or HICO) for the detection of these large surface blooms. Also, we found a continuum of spatial scales with the dominant scales being 150 to 300 m depending on the image analyzed. For this data 60 to 80% of the spatial information in the Monterey Bay scene is resolved at 100 m (**Fig. 3**). This is indicative of the spatial scales of water column features in coastal waters including fronts, algal blooms and slicks. Thus a system designed for sampling the water column only can be designed to sample at 100 m. HICO is designed to meet the requirements for imaging the coastal ocean. It has a 100 m Ground Sample Distance (GSD) and samples 400 - 1000 nm in 5.7 nm spectral channels.

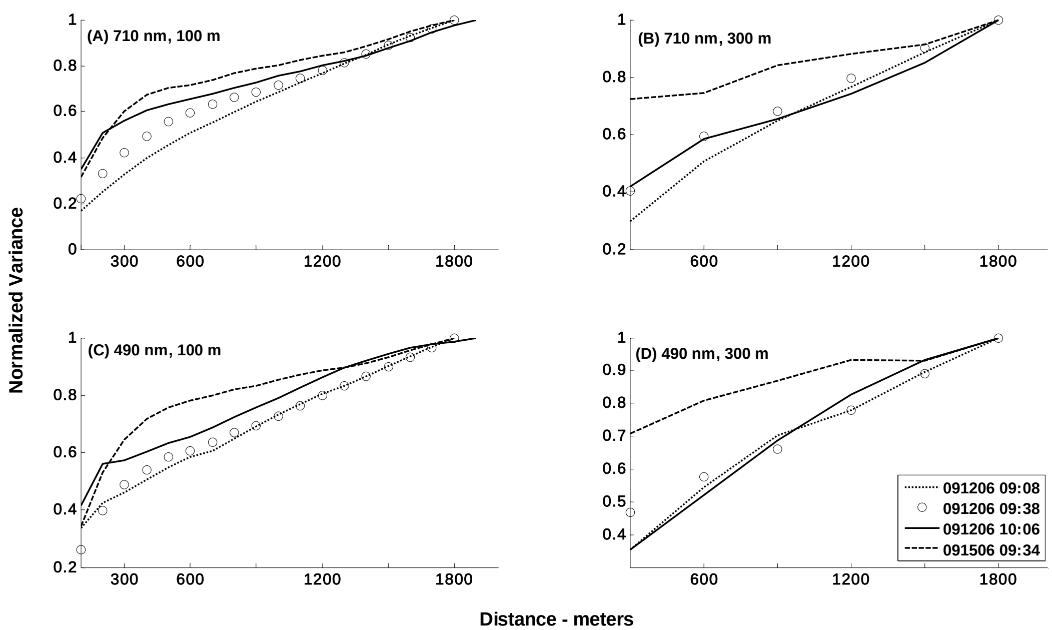
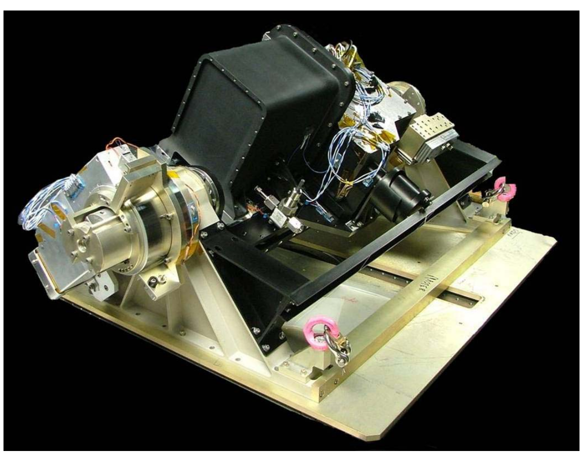


Fig. 3. Airborne hyperspectral data for Monterey Bay binned to 100 m (a, c) and 300 m (b, d). For these optically deep waters 100 m data was adequate to resolve 60 to 80% of the variability in the scene (the unresolved variance or nugget (c_0) is 0.2 to 0.4). The 300 m data only resolved 60% to as little as 30% of the variability.

While HICO is now flying on the ISS I continue to support the Naval Research Laboratory in the effort to fly COIS (Wilson and Davis, 1999) on a spacecraft of opportunity to provide higher resolution hyperspectral data for the coastal ocean. Each year we have presented COIS to the Navy and DoD Space Experiment Review Boards (SERBs) and received high rankings. The current ranking for COIS is 4 out of 30 on the 2008 Navy SERB list and 5 out of 62 on the 2008 DoD SERB list. While HICO data will be 100 m GSD optimal for characterization of optically deep coastal waters, COIS would provide the 30 m GSD data optimal for optically shallow waters producing products like bathymetry and bottom types.

The Hyperspectral Imager for the Coastal Ocean (HICO; Corson et al. 2008) is an imaging spectrometer based on the PHILLS airborne imaging spectrometers (Davis et al. 2002). HICO is the first spaceborne imaging spectrometer designed to sample the coastal ocean. HICO will sample selected coastal regions at 100 m with full spectral coverage (380 to 1000 nm sampled at 5.7 nm) and a high signal-to-noise ratio to resolve the complexity of the coastal ocean. HICO is sponsored by the Office of Naval Research as an Innovative Naval Prototype (INP), and will demonstrate coastal products including water clarity, bottom types, bathymetry and on-shore vegetation maps. As an INP, HICO also demonstrates innovative ways to reduce the cost and schedule of this space mission by 80% by adapting proven PHILLS aircraft imager architecture and using Commercial Off-The-Shelf (COTS) components where possible.

The HICO program was initiated in February 2006. In January 2007 HICO was selected to fly on the Japanese Experiment Module Exposed Facility (JEM-EF) on the International Space Station. Construction began following the Critical Design Review on November 15, 2007. HICO was completed in July 2008 (**Fig. 4**) and it was integrated into the HICO and RAIDS Experimental Payload (HREP) in August 2008. HICO is integrated into HREP and flown with support and direction from DOD's Space Test Program. HREP has completed environmental testing at NRL and NASA's Marshall Space Flight Center and was shipped to Japan on April 9, 2009. HREP was launched on the H-2 Transfer Vehicle (HTV) September 10, 2009. The HTV rendezvoused with the ISS on September 17, 2009. HICO was installed on September 23 (**fig 4**) and collected its first images on September 24, 2009. The image quality looks excellent and the team is assessing the calibration and testing processing systems. Data should be available for distribution in October or November.



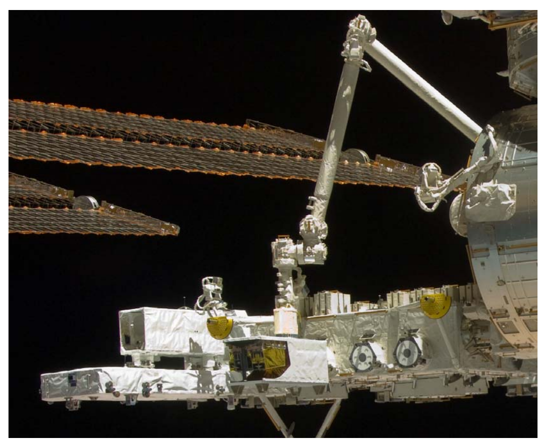


Fig. 4. Left, The HICO Flight Hardware which was completed in July 2008. HICO was launched to the International Space Station on September 10, 2009. Right HREP is being installed on the ISS using the Japanese Arm on September 23, 2009. RAIDS is the gold covered instrument in the front of HREP and HICO is housed in the white section at the back of HREP.

As HICO project scientist, I am funded by NRL to continue to work with the engineers and scientists at NRL and partner institutions to prepare for the processing and analysis of HICO data. The NRL team will process the HICO data to standard products. At OSU we will have an identical copy of the HICO processing system and will process and distribute data for academic users and international partners.

RESULTS

The focus of this effort is on the processing and analysis of existing data sets and the publication of results and new algorithms based on that data and on papers that explain the value and importance of hyperspectral imaging of the coastal ocean. During the first year of this project we developed and published a description of an IOP profiling system (Rhea, et al., 2007) that provides real-time IOP data and the ability to collect water at selected depths based on that data. Then we published a paper (Snyder, et al., 2008) on the optical measurements collected with that system describing a diversity of US coastal waters. Another paper (Lee et al., 2007) describes the development of a new method for atmospheric correction and processing of Hyperion data from the Florida Keys.

HICO has been completed integrated into HREP and is now installed on the ISS. HICO is the first imaging spectrometer designed for coastal ocean imaging to be flown in space. HICO is operating as planned and the initial data products look very good. We look forward to working with the NRL team on the on-orbit calibration and validation of HICO products for the coastal ocean in the next few months. As Project Scientist I will work with the scientific community to make the best possible use of this unique data set.

IMPACT/APPLICATIONS

The long term goal of this work is demonstrate the value of a hyperspectral imager capable of making the appropriate measurements in space to demonstrate the capability of this technology for the rapid and covert characterization of the coastal ocean to support naval operations around the world. We will use data from HICO on the ISS to demonstrate that capability beginning in the fall of 2009. The work completed this year is another incremental step towards that goal.

RELATED PROJECTS

I continue to collaborate regularly with colleagues at the NRL Remote Sensing Division (Code 7200; Mike Corson and others) and the NRL Oceanography Division (Code 7300; Bob Arnone and others) and with Zhong-Ping Lee at Mississippi State University.

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